Title: **Are attitudinal and perceptual body image the same or different? Evidence from high-level adaptation.**

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Abstract

We used a high-level adaptation paradigm to distinguish between two hypotheses: i) perceptual and attitudinal body image measurements reflect conceptually different mechanisms which are statistically independent of each other; ii) attitudinal (e.g., questionnaire) and perceptual (e.g., visual yes-no) body image tasks represent two different ways of measuring exactly the same construct. Forty women, with no history of eating disorders, carried out the experiment. Each participant carried out five adaptation blocks, with adapting stimuli representing female bodies at: extreme-low body mass index (BMI), mid-low BMI, actual BMI of the observer, mid-high BMI and extreme-high BMI. Block order was randomized across participants. The main outcome variable was percentage error in participants' self-estimates of body size, measured post-adaption. In regressions of this percentage error on the strength of the adapting stimuli together with observers' attitudinal body image as a covariate, we found positive regression slopes and no evidence for any interaction between the fixed effects. Therefore, we conclude that perceptual and attitudinal body image mechanisms are indeed independent of each other. In the light of this evidence, we discuss how people with eating disorders, like anorexia nervosa, may come to over-estimate their body size.

Keywords: Adaptation, body image, attitudinal, perceptual, body size, anorexia nervosa

Introduction

According to the influential meta-analysis by Cash and Deagle (1997), perceptual body image represents the accuracy with which a person can judge the physical dimensions of their own body (see also: Gardner & Brown, 2014; Mölbert, Klein, Thaler et al., 2017; Skrzypek, Wehmeier, & Remschmidt, 2001). Attitudinal body image captures the feelings that a person has about their body size and shape. In this study, we use an adaptation paradigm to ask whether perceptual body image measures are really a proxy for attitudinal body image, which is usually assessed psychometrically, or whether these are indeed meaningfully separate, statistically independent constructs.

The problem

How can we measure perceptual body image in such a way that we can decide unambiguously whether it is the same or different from attitudinal body image? All models of our perceptual ability to detect a stimulus or discriminate between stimuli comprise at least two component processes: i) a sensory process which transforms physical stimulation into internal sensations, and ii) a decision process which generates responses based on the output of the sensory process (Krantz, 1969). In principle, signal detection theory allows us to estimate both components (Gescheider, 1997; Green & Swets, 1966). To be concise, an observer's ability to perform a detection/discrimination task is limited by internal noise. The decision that an observer makes on any trial of such a task, such as if a stimulus is present or not, is driven by two factors: (i) the information they have (e.g., signal strength) and (ii) the criterion or internal bias that an individual sets for making a decision. Because there are two factors (signal strength and criterion) determining the outcome of each trial, two measurements are needed to characterize the role of the two factors in task performance. Typically, for a yes-no task, the hit rate (i.e., correctly stating that a stimulus was present when it actually was) and the false positive rate (i.e., incorrectly stating that a stimulus was present when it was not) can be used to calculate sensitivity to the signal (d-prime) and bias (C). Therefore, in principle, signal detection theory could be used to analyse data from a typical visual psychophysical task of the kind used to estimate body size.

Smeets, Ingleby, Hoek, and Panhuysen (1999) carried out such an experiment by asking female patients with anorexia nervosa (AN) and healthy controls to judge pairs of images using the method of constant stimuli. On each trial, participants saw two images of a body, side by side. In their key experiment, one image, the reference, was an image of the participant, and the other was an image of the participant which was compressed/stretched in the horizontal dimension to mimic a change of body adiposity. Participants were asked to judge whether the pair of images was the same or different. Smeets et al. (1999) applied a signal detection analysis which preserved the directions of the stimulus size changes (i.e., thinner or fatter), and showed that patients with AN had a significant bias for responding "thinner than", even though they were just as sensitive in the detection of a size difference as controls. However, while the Smeets et al. (1999) study shows how signal detection theory can successfully be applied to judgements about images of bodies, it also illustrates the difficulty with applying signal detection theory to self-estimates of body size: i.e., "what size do I believe I am?" To do this, one would need to be able to manipulate the signal in a predictable way (i.e., a participants' belief about their body size), for example by distorting it by known amounts. Almost by definition this seems impossible, because both the signal and the observer bias reside in the mind of the observer and cannot be accessed directly. Instead the Smeets et al. (1999) study addresses the question "how sensitive am I to telling apart those two pictures of me?", and this question can be answered without making any reference to the size the participant believes themselves to be. In short, our ideal approach, using signal detection theory to reveal a true perceptual component to judgements about one's own body image, appears to be blocked.

Given this apparently irreconcilable difficulty with applying signal detection theory to self-estimates of body size, we turn therefore to studies which have used the method of constant stimuli and have applied classical psychophysical methods to measure: (i) the point of subjective equality (PSE) which corresponds to the body size that participants believe themselves to have; (ii) the difference limen (DL) which corresponds to how sensitive a participant is to detecting changes in body size (see e.g., Cornelissen, Bester, Cairns, Tovée, & Cornelissen, 2015; Cornelissen, McCarty, Cornelissen, & Tovée, 2017; Gardner & Bokenkamp, 1996; Gardner, Jones, & Bokenkamp, 1996; Mölbert, Thaler, Mohler, Streuber, Romero, Black, et al., 2018). The problem with all these studies is that both the PSE and DL are influenced by the subjective states of the observer – for example their expectancies about the stimuli (Gescheider, 1997). In short, both the PSE and DL are prone to bias. The substantive literature on the effects of attitudinal body image on body size estimation tasks (see e.g. Cornelissen, Johns, & Tovée, 2013; Fernandez Aranda, Dahme, & Meermann, 1999; Gardner & Bokenkamp, 1996; Smeets, Ingleby, Hoek, & Panhuysen, 1999) suggests that this bias could be directly related to participants' attitudes about their body image. Taken to its logical conclusion, this suggests that if individual variation in PSE and DL is primarily driven by variation in attitudinal body image, then what purport to be *perceptual* body image tasks may actually be visual versions of *attitudinal* body image tasks. So it is logically possible that attitudinal (e.g., questionnaire) and perceptual (e.g., visual yes-no) tasks may represent two different ways of measuring exactly the same thing. Therefore, in this study we will attempt to differentiate two positions: i) that perceptual and attitudinal body image measurements are different concepts which are statistically independent of each other; ii) that perceptual and attitudinal body image measurements are really estimates of the same underlying attributes.

Alternative interpretations

Cornelissen et al. (2015, 2017) investigated perceptual body image in women with a history of AN and healthy controls. They asked participants to visually estimate their body size using CGI stimuli in a yes-no task together with the method of constant stimuli. Figure 1a illustrates their key findings. Control participants with a low body mass index (BMI) over-estimated their size and those with a high BMI under-estimated, a pattern which is consistent with a normal perceptual phenomenon called contraction bias (Poulton, 1989). In contrast, the women with a history of AN who had a low BMI were both extremely accurate at estimating visually presented body size and very sensitive to small changes in BMI. However, as BMI rose in this group, their body-size over-estimation rose rapidly in direct proportion to their increasing BMI. Critically, as is illustrated in Figure 1a, visual body size estimation in both groups also depended simultaneously on attitudinal factors indexed by performance on psychometric tasks measuring attitudes towards body shape, body size and eating habits. Specifically, the intercepts for the regression lines for both the women with AN and the healthy controls were controlled by attitudinal factors. Taken at face value, these data can be interpreted as showing independent influences of both perceptual judgements (controlling the slopes of the regression lines) and attitudinal body image (controlling the intercepts) on body size estimates, with no statistical interaction between the two. However, to follow our earlier line of argument, let us assume that the perceptual judgements are really a visual proxy for body attitudes which we know empirically are also correlated positively with BMI (cf. Cornelissen et al., 2015; Irvine, McCarty, McKenzie, Pollet, Cornelissen, Tovée et al., 2018). This leads us to a very different interpretation of the same graph. First, the outcome variable (y-axis) would in fact amount to an estimate of *attitude* rather than body size. Secondly, the x-axis would correspond to a pedestal value, in each participant, for a measured component of attitudinal body image. This is plausible because BMI is correlated with attitudinal body image. Therefore, under this argument, we would effectively be substituting body attitude for BMI on the x-axis. Consequently, a regression of estimated attitude (y-axis) on measured attitude (x-axis) would still have a positive slope, because attitude and BMI are correlated, as in Figure 1a. But in addition, the intercept could also be influenced by variation in other attitudinal measures (e.g., the body shape questionnaire [BSQ, Evans & Dolan, 1993] or the Eating Disorders Examination Questionnaire [EDE-Q, Fairburn & Beglin, 1994]) as originally described. In short, Figure 1a can be re-interpreted entirely in terms of attitudinal body image alone. So, how can we tell which of these two possibilities is correct? How do we avoid what amounts to a re-labelling problem? Here, we argue that what is needed is an experimental design that moves beyond patterns of correlations from single point estimates per participant across a number of tasks, e.g., one perceptual task estimate, and, say, four attitudinal task estimates, one data point per participant from each task. Instead, we need an experimental manipulation that produces a number of different estimates from the putative perceptual task in each participant. In addition, we need clear predictions about what we would expect the relationship to be between these putative perceptual judgements and attitudinal body image under the two different hypotheses.

Visual Adaptation

Visual adaptation is a temporary change in sensitivity or perception following prolonged exposure to a new or intense stimulus. It leads to a lingering aftereffect that may persist once the adapting stimulus is removed (Webster, 2011). Low-level visual adaptation is well documented and tends to produce aftereffects which give rise to a percept that has the *opposite* sign to the adapting stimulus. A classic example is the waterfall illusion. After watching the motion of the water in a waterfall, and then attending to a stationary scene, for example the rocks by the side of the waterfall, the ‘stationary scene’ appears to drift upwards (Blakemore, 1973; Frisby, 1979). High-level adaptation effects also exist that result in aftereffects that change in the *same* direction as the adapting stimulus. For example, face aftereffects have been demonstrated for facial properties like emotional expression (Fox & Barton, 2007; Webster, Kaping, Mizokami, & Duhamel, 2004), ethnicity (Ng, Boynton & Fine, 2008; Webster, Kaping, Mizokami, & Duhamel, 2004), gender (Webster, Kaping, Mizokami, & Duhamel, 2004), and gaze direction (Calder, Beaver, Winston, Dolan, Jenkins, et al., 2007). In the case of gender, after adapting to a male face, a previously ambiguous image (perceptually midway between male and female) appeared distinctly female, and thus the image that now appeared neutral was shifted towards being male. With respect to whole bodies, Winkler and Rhodes (2005) compared participants’ ratings of the attractiveness and perceived normalcy of images of female bodies before and after exposure to either extremely narrow or extremely wide bodies. Post-adaptation, they found that participants rated significantly narrower bodies as most attractive and normal following exposure to extremely narrow bodies. Similar results were found by Hummel and colleagues (2012). In two experiments these authors adapted healthy females to pictures of either thin or fat bodies and then asked them to compare more or less distorted pictures of their own body to their actual body shape. These authors used images of self, or others to manipulate identity. They found that after adaptation to a thin body, participants rated a thinner than actual body picture to be the most realistic and vice versa, irrespective of identity. Thus, high-level visual adaptation fulfils our criteria for the choice of experimental paradigm, because it provides a number of different response outcomes per participant, in this case parametrically related to the strength of the adapting stimuli.

The current study

Perceptual and attitudinal body image are independent

According to the independence hypothesis, we would expect the perceptual component of participants' responses in an adaptation paradigm to mirror the findings of Hummel, Rudolf, Untch, Grabhorn, and Mohr (2012). Specifically, if a participant adapts to images of bodies that are thinner than they believe themselves to be, in a post-adaptation body size estimation task they should under-estimate their body size. If we define percentage error in the post-adaptation task as: [estimated BMI post-adaptation] - [Actual BMI] / [Actual BMI] × 100, then under-estimates of body size correspond to negative percentage error. By contrast, if a participant adapts to images of bodies that are heavier than they believe themselves to be, they should over-estimate their body size post-adaptation (i.e. positive percentage error). Therefore, a regression of percentage error in body size estimation on the adapting stimulus should have a *positive* slope. With respect to the attitudinal component of participants' responses, we expect an independent, additive component. This should scale linearly with increasing body image concerns, thereby controlling the regression line intercept, in line with Cornelissen et al. (2015, 2017) as shown in Figure 1a. Critically, there should be *no* interaction between the adapting stimulus and body image concern, as illustrated in Figure 1b.

Perception as a proxy for attitude

We want to test the hypothesis that visually presented body size estimation tasks are really estimates of body attitudes by proxy. If so, we need to imagine what to expect from a conventional adaptation task *if*, under this hypothesis, the stimuli represent varying pressure to adapt body *attitude*, and the outcome is an estimate of changes in body *attitude*, and *not* perceptual judgements about body size. To anticipate, based on social comparison theory (Festinger, 1954), an individual who has very few concerns about their body may not be very susceptible to the appearance of someone else who is slimmer, nor be inclined to feel superior to someone who is larger. Consequently, not only will they have low body image concerns overall, but they should also show little change in body attitude in response to adaptation. However, an individual who would prefer to be much thinner may be upset that theirs is not the body of a much slimmer individual, but still grateful that they do not have a much larger body. Such an individual would be expected to have high body image concerns overall, coupled with marked sensitivity to adaptation. In a standard adaptation paradigm, participants are asked to respond by selecting from an array of images that vary continuously in adiposity. Under the ‘perception as attitude’ hypothesis therefore, we argue that body attitude should be directly correlated with the body size of the image chosen as the response: specifically increased body image concerns should lead individuals to cartoon their distressed feelings by selecting images of heavier bodies, and decreased body image concerns should lead to their selecting images of thinner bodies.

To flesh out the argument in more detail, let us consider running an adaptation task in which a participant is shown an image of a body that is the same size as they believe themselves to be. Because there is no discrepancy between the stimulus and the participant, there should be no pressure for the participant’s own body attitude to change. Under the ‘perception as attitude’ hypothesis therefore, the participant’s responses in the test phase following the adaptation period should correspond to their pre-existing body attitude before testing began, i.e. their pedestal body attitude. They should therefore select an image from the response set that cartoons this prior state.

Let us now consider what we would expect to see if, during the adaptation phase, a participant is presented with an image of a body that is thinner than they believe themselves to be. According to social comparison theory, this should represent an aspirational stimulus which should be the cue for upward social comparison. The thinner the body the stronger the cue to adapt. Moreover, the consequence to the participant of making such a social comparison should have a negative impact on their own body attitudes: the thinner the adapting stimulus, the *greater* their body image concerns should become. Consequently, to cartoon this change in attitude, they should select a response image which is fatter than they believe themselves to be. If, however, during adaptation, a participant is presented an image of a body that is fatter than they believe themselves to be, this stimulus should represent a cue for downward social comparison. Moreover, the fatter the body, the stronger the cue, so that fatter bodies lead to systematically larger *reductions* in body image concerns. Now, to cartoon this change in attitude, they should select a response image which is thinner than they believe themselves to be.

To summarise, a ‘thinner than’ adaptation stimulus creates an upward social comparison leading to increased concerns and a ‘heavier than’ response. In contrast, a ‘heavier than’ adaptation stimulus creates a downward social comparison leading to decreased concerns and a ‘thinner than’ response.

While this describes the direction and relative magnitude of the drive for attitudinal adaptation to a particular stimulus, we propose that the *net* effect on body attitude must also incorporate a participant’s pedestal body attitude, as revealed by exposure to the same size body condition. Therefore, under the ‘perception as attitude hypothesis’, a simple multiplicative model of body image adaptation would include: i) multiplying, or scaling, the magnitude and sign of the adapting stimulus by the magnitude of the attitudinal state the individual is already in and ii) adding this to their pedestal body attitude. As a concrete example, using uncalibrated numbers for the sake of illustration, let an individual who has very few concerns about their body image score 2 on an attitude scale (ranging from 0 - 10), whereas another individual who has very many concerns might score 7 on the same scale. With respect to the adaptation paradigm, let the relative strength of the adaptation cue be determined by both the magnitude of the multiplier, as well as its sign; positive for upward social comparison and negative for downward social comparison. Hence, in an experiment with five different body sizes to which the participant is adapted, we might have: +0.2 (much smaller body), +0.1 (smaller body), 0 (same size body), -0.1 (larger body), and -0.2 (much larger body). Accordingly, for the participant whose pedestal body attitude at image size 0 is 2 (i.e. low body image concerns), their net estimates of body attitude across the 5 adaptation levels should be: 2 + (0.2 x 2), 2 + (0.1 x 2), 2 + (0 x 2), 2 + (-0.1 x 2) and 2 + (-0.2 x 2), i.e. 2.4, 2.2, 2.0, 1.8, & 1.6. This represents a difference of 0.2 between successive adaptation levels. For the participant whose pedestal body attitude is 7 (i.e. high body image concerns), the corresponding post-adaptation values should be: 7 + (-0.2 x 7), 7 + (-0.1 x 7), 7 + (0 x 7), 7 + (0.1 x 7) and 7 + (0.2 x 7), i.e. 8.4, 7.7, 7.0, 6.3, & 5.6. This represents a difference of 0.7 between successive adaptation levels. This simple linear scaling scenario is represented in the sketch graph in Figure 1c. It shows that a regression of percentage error on the adapting stimulus should have three key features: i) the slopes of the regression lines should be negative, ii) the intercepts of the regression lines should increase linearly as a function of increasing body image concern, and iii) the slopes of the regression lines should systematically become steeper with increasing body image concerns, and this should be reflected in a linear interaction term between the strength of the adapting stimulus and a direct measure of body image concern; one should depend on the other.

Other, slightly more subtle effects are also possible. For example, individuals whose current attitudinal state is already moderately or severely disturbed might be strongly effected by a downward social comparison (larger bodies). However, they may nevertheless be refractory to further distress when presented with an upward social comparison (smaller bodies), because their distress is already at ceiling. Such a possibility is illustrated in Figure 1d, where there is no change in percentage error for the ‘much smaller’ and ‘smaller’ adaptation stimuli. Statistically, this subtler scenario should still be revealed by a significant linear interaction between the adaptation parameter and the current attitudinal state of the observer.

There are other mechanisms which could also plausibly reproduce patterns of adaptation effects similar to Figure 1c. For example, the degree and focus of attention that a participant can give to the adapting stimuli might be correlated with the strength their body image concerns. Attending more closely to the adapting stimuli may magnify the adaptation effect in post-test. If so, the systematic change in regression slopes shown in Figure 1c (i.e. stronger adaptation at higher levels of pedestal body image concern) could be attributed to an interactive influence of attention. Moreover, statistically, this scenario would also be reflected in a significant linear interaction between the strength of the adapting stimulus and a direct measure of body image concern. Nevertheless, the logic of this study is not undermined by such alternative explanations. If we observe negative regression slopes together with a statistically significant interaction, it means we can rule *in* the perception as attitude hypothesis, as well as alternatives, which include a role for visual attention. But critically, we can also rule *out* the independence model. However, if we find positive regression slopes and no compelling evidence for a linear interaction term, it means we can rule *in* the independence model, and rule *out* the alternatives, including the perception as attitude hypothesis.

Method

The experimental procedures and methods for participant recruitment for this study were approved by the **** *blinded* **** University Ethics Committee.

Participants

We used GLIMMPSE (General Linear Multivariate Model Power & Sample Size; Kreidler, Muller, Grunwald, Ringham, Coker-Dukowitz, Sakhadeo, et al., 2013) to estimate the sample size required for this study, based on data from a pilot study with 13 participants. Choosing a scale factor of 1 for variability and main effect size showed that a sample of 12 participants would achieve a power of 0.9 at an alpha level of .05. A more conservative calculation with double the variability and half the effect size rendered sample sizes of 41 and 51 participants to achieve a desired power of 0.8 and 0.9 respectively. Based on these estimates, we recruited 40 participants (age *M*= 23.75 years, *SD*= 6.48) from staff and students at **** *blinded* **** University. Participants were eligible to take part if they were female (as assigned at birth), had no history of current or previous eating disorders, and had normal or corrected to normal visual acuity. Participants' body mass indices (BMI) ranged from 17.20 to 39.90 (*M*= 24.43, *SD*= 4.91) and fell into the following WHO categories: 1 underweight, 26 normal, 8 overweight, 3 obese, and 2 severely obese.

Stimuli

Stimuli were selected from the database of 160 CGI (computer-generated imagery) images of a standard female model as described in Cornelissen, McCarty, Cornelissen, and Tovée (2017), whose BMI ranged from 12.5-55. The images were created with DAZ v4.8 and were calibrated for BMI, based on the waist and hip circumference data from the Health Survey for England (HSE 2003 & 2008). They were rendered in Luxrender. The advantages of this stimulus set are that the images: (i) are high definition and photorealistic, (ii) maintain the identity of the female model across a wide BMI range, and (iii) demonstrate extremely realistic changes in BMI dependent body shape.

Assessment

Psychometric and anthropometric measures.

To measure the attitudinal component of body image, participants completed the following self-report questionnaires that measure body satisfaction, tendency towards depression, and self-esteem: (i) the 34-item Body Shape questionnaire (BSQ-34) (range 0-204; Cooper, Taylor, Cooper, & Fairburn, 1987) was used to assess participants' weight concerns and attitudes towards their body shape; (ii) the Beck Depression Inventory (BDI) was used to measure levels of depression (range 0-63; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961); iii) the Rosenberg Self-Esteem Scale (RSE) (range 0-30; Rosenberg, 1965) was employed to measure participants' self-esteem. Participants were also required to complete a visual analogue scale (VAS) upon finishing each of the five adaptation blocks. The VAS questioned participants on their psychological state throughout the experiment. It asked how positive/good or negative/bad participants would rate their current mood. Finally, each participant's body mass index (BMI) was calculated from their weight and height measured with a set of calibrated clinical SECA scales and a stadiometer respectively. See Table 1 for these descriptive statistics.

Psychophysical measurement

Participants used a method of adjustment (MoA) task to estimate their body size with the same stimulus set as for the adaptation paradigm (cf. Sturman, Stephen, Mond, Stevenson, & Brooks, 2017; Stephen, Sturman, Stevenson, Mond, & Brooks, 2018; Stephen, Hunter, Sturman, Mond, Stevenson, & Brooks, 2018). On each trial, the stimulus appeared on screen, and beneath the stimulus was a slider control (see Figure 2). The participant was asked to click on the slider control to drag it from side to side. When the slider moved leftwards the BMI of the model reduced smoothly to a minimum of 12.5 and increased to a maximum of 50.0 when the slider moved rightward. The participant had to decide what body size of the stimulus best matched the body size they believed themselves to have, and then press a radio button, marked 'Continue', on screen that allowed the stimulus PC to log their response and initiate the next trial. At the start of each trial, the BMI of the model was set randomly to either its minimum, with the slider appearing at the leftmost extreme of its range of movement, or the maximum

BMI, with the slider appearing at the rightmost extreme of its range of movement. Figure 2 illustrates screenshots from this task.

Adaptation task

The adaptation procedure was controlled by a Python programme written by one of the authors. It consisted of five blocks of trials: extreme low BMI, mid low BMI, actual BMI, mid high BMI, and extreme high BMI, with block order randomized across participants. Within each of the blocks, participants were presented 20 stimuli for adaptation that fell within a 2 BMI unit range, and each set of 20 images was presented three times, giving a total of 60 trials per adaptation block. The BMI ranges for each of the five blocks were: extreme low BMI (14-16), extreme high BMI (45-47), participant's actual BMI (+/- 1 BMI unit), and the midpoints between the extremes and participant's actual BMI (+/- 1 BMI unit). For example, if a participant's actual BMI was 25, then the range of BMIs in the stimuli presented for the actual BMI adaptation block would be 24-26. Moreover, the midpoint between the middle of the low-extreme block and the participant's actual BMI would be 20. Therefore, for adaptation at the mid-low BMI block of trials, participants were presented images between 19-21 BMI units. All stimuli were presented on a 13" LED-backlit widescreen laptop (1280 w x 800 h pixel native resolution) at a viewing distance of approximately 70cm.

In order to keep participants as fully engaged as possible during the adaptation procedure, we ran it as a match to sample task. During each of the 60 trials, one of the 20 images for that block was presented for four seconds on a neutral gray background. After four seconds, the single image was replaced by a pair of images arranged side by side. Participants had to select by button response whether the image to the left or right was the image they had just been shown. They were asked to make this choice as quickly and accurately as possible. The foil image was a random pick between the lowest and the highest BMI image from the BMI range for that particular adaptation block, with equal probability of being chosen across the 60 trials. In addition, the target stimulus had an equal probability of appearing in the left or right location across the 60 trials. By running the adaptation task in this way meant that participants spent approximately five minutes engaged with looking at images within a narrow, 2 BMI unit range.

Procedure

Consenting participants completed the psychometric questionnaires, had their height and weight measured and were informed that the purpose of the experiment was to assess the accuracy of their judgements about their own body size, as well as the body size of others. They were not informed that exposure to the images might affect their perceptual judgements. A full explanation and debrief was given at the end of the experiment.

Before adaptation began, participants completed ten trials of the MoA to obtain a baseline self-estimate of their body size. This lasted for approximately five minutes. Next, to measure any effect of adaptation, participants were required to carry out four consecutive sequences of body size estimation trials followed by a top-up adaptation. Each of the four sequences comprised: i) three MoA trials, ii) an 8 second presentation of a top-up stimulus, iii) a one second blank inter-stimulus interval (ISI). The top-up stimulus corresponded to the middle of the BMI range for that adaptation block. By the end of each adaptation block, we had obtained 12 post-adaptation judgements of body size. Before participants started the next adaptation block, they completed the VAS and a short digit span test. The whole experimental procedure took approximately 90-120 minutes for each participant to complete and the sequence of events is outlined in the flow diagram in Figure 3.

Results

Univariate Analysis

The internal reliability of the psychometric measurements was good. Cronbach's alpha for the BSQ, RSE, and BDI was 0.97, 0.69, and 0.82 respectively. Descriptive statistics for the 40 female participants are presented in Table 1. The means and standard deviations found for BDI and RSE show scores which are consistent within the lower and normal ranges for these tests. In addition, the mean

BSQ-34 score (*M* = 89.3, *SD* = 34.46) was within 1 *SD* of the range observed in a healthy control population of 407 adult females (Probst, Pieters, & Vanderlinden, 2008).

To calculate the post-adaptation aftereffect, separately for each participant and for each adaptation level, we calculated the percentage error between the mean of the MoA body size estimates and the participant's BMI: specifically (mean MoA - BMI) / BMI × 100. Negative values represent under-estimation while positive values represent over-estimation. Participants showed good internal reliability for post-adaptation body size estimation and VAS scores across the five levels of adaptation, with Cronbach's alpha of 0.99 and 0.98 respectively.

Multivariate Analysis

We analysed the adaptation data in two ways. In the first analysis, we classified the strength of the adapting stimulus as belonging to one of five levels, relative to the BMI of the participant: i.e. extreme low, mid low, actual, mid high, and extreme high. In this analysis, therefore, adaptation strength was treated as a class variable in the multivariate models, and dummy coded accordingly. However, it is also true that while the BMI of the extreme low and extreme high adapting stimuli were always 15 and 46 respectively, nevertheless the BMI of the participant was variable. This meant that the BMI of the mid low and mid high adapting stimuli was also variable. As a result, the distribution of adaptation strength, when treated as a continuous variable, was not normal. Therefore, we also ran a second analysis in which we treated adaptation strength as a continuous variable, but used linear mixed effects modelling in combination with bootstrapping to produce robust estimates of the regression parameters and their confidence intervals.

Adaptation strength coded as a class variable

Figure 4a shows box plots for post-adaptation percentage error in body size estimation as a function of the adapting stimulus. It illustrates two important attributes in the data. First, there was a tendency for the mean of the post-adaptation aftereffect to increase systematically across the range of the adapting stimuli from 'extreme low' to 'extreme high'. Secondly, there was wide variability in percentage error at all adaptation levels, encompassing under-estimation to over-estimation of body size.

We wanted to understand the relationship between post-adaptation aftereffects and participants' attitudes about their bodies, tendency towards depression and self-esteem, as indexed by the BSQ, BDI, and RSE. The hypothesis that perceptual and attitudinal body image correspond to independent levels of body image representation predicts positive regression slopes and statistically independent contributions from, for example, BSQ and adaptation in modelling post-adaptation body size estimates. By comparison, the hypothesis that perceptual body image is a proxy for attitudinal body image, because they are really measures of the same thing, predicts negative regression slopes and a statistical interaction between, for example, BSQ and adaptation in modelling post-adaptation body size estimates.

To distinguish between these two hypotheses we used PROC MIXED (SAS v9.4) to build a linear mixed effects model of post-adaptation percentage error in body size estimation. We tested as putative fixed effects: adaptation (5 levels: extreme low BMI, mid low BMI, actual BMI, mid high BMI, and extreme high BMI), BSQ, RSE, BDI, and age. Critically, we also tested all possible two-way interaction terms. The final model was optimized by ensuring that i) any fixed effect retained in the model contributed a statistically significant reduction in -2 Log Likelihood, ii) fixed effects were retained in a model only if their Type III test of fixed effects was significant at $p < .05$. The only exceptions to this would have been where one non-significant fixed effect comprised part of a significant two-way interaction term, in which case it would have been retained. In addition, we permitted individual variation at the intercept level for each observer, by including a random intercept term. Note, we used the extreme high BMI level as the control when dummy coding adaptation. The detailed outcome of the statistical modelling is shown in Table 2. It shows that only adaptation and BSQ accounted for variance in percentage error in body size estimation; RSE and BDI played no part. Critically, we did not find a statistically significant interaction between the adapting stimulus and BSQ ($F(4,152) = 0.69$, $p = .60$).

To visualize the model outcome, we computed LSmean percentage errors (i.e., the marginal means) predicted from the optimized model, together with their 95% confidence intervals, at three representative levels of BSQ score: 40, 100, and 160. This is illustrated in Figure 5a which shows three key features: i) the effect of increasing body image concerns (i.e., increasing BSQ) is to systematically increase body-size estimation, at any given level of adaptation; ii) the overall effect of adaptation from one extreme adapting BMI range to the other is to systematically increase body-size estimation from one adaptation step to the next; iii) the least amount of adaptation is to be found where one might intuitively expect it, i.e., in individuals with the lowest BSQ scores who are presented adaptation stimuli centred on their own actual BMI.

Competition between models

As a last step we used the Akaike information criterion (AIC; Akaike, 1973) and Bayesian information criterion (BIC; Schwartz, 1978) to compare the relative adequacy of the null model, the model including the interaction between the fixed effects and the model without the interaction. To do this, we transformed the AIC and BIC values to weights that can be directly interpreted as conditional probabilities to compare between models (Wagenmakers and Farrell, 2004). First, we calculated, for each model, the differences in AIC and BIC with respect to the AIC and BIC of the best candidate models. From the differences in AIC, we then obtained an estimate of the relative likelihood *L* of each model *i* by the transform:

$$L(M_i \mid \text{data}) \propto exp\left\{-\frac{1}{2}\,\Delta_i(\text{AIC})\right\}, \qquad (1)$$

where ∝ stands for “is proportional to”. Finally, the Akaike weight for each model w_i(AIC) is obtained by dividing its relative likelihood by the sum of the likelihoods of all three models, such that:

$$w_i(\text{AIC}) = \frac{exp\left\{-\frac{1}{2}\Delta_i(\text{AIC})\right\}}{\sum_{k=1}^{K} exp\left\{-\frac{1}{2}\,\Delta_i(\text{AIC})\right\}} \qquad (2)$$

We used a similar procedure to calculate the BIC model weights, w_i(BIC), by replacing the AIC values in equation (2) with BIC. The results are shown in Table 3, from which we can calculate the evidence in favour of the no interaction model compared to the model with interaction. To do this, we calculate the ratios of their respective weights which are, for AIC and BIC respectively, 0.9286/0.0724 = 12.83 and 0.9973/0.0027 = 369.37. In short, using AIC, the evidence for the no interaction model is 12.83 times stronger than that for the model with interaction. Using BIC, the evidence for the no interaction model is 369.37 times stronger than that for the model with interaction.

In the design of this adaptation experiment, it would not have been logistically feasible, or even legitimate to take multiple repeated measures of the three psychometric tasks. Instead, we relied on the VAS to monitor attitudinal changes across adaptation blocks. Table 4 shows the Pearson correlations between the VAS after each adaptation block and BSQ, BDI, and RSE. The VAS, BSQ, and BDI are moderately correlated across time justifying this decision.

Figure 4b shows box plots for post-adaptation VAS responses as a function of the adapting stimulus. It illustrates that the mean VAS response tends to be lowest for the actual BMI adaptation block, and then increases systematically by small amounts towards either extreme. To model the relationships between VAS, adaptation and the psychometric tasks we used PROC MIXED (SAS v9.4) to build a second linear mixed effects model. As before, we included the putative fixed effects: adaptation (5 levels: extreme low BMI, mid low BMI, actual BMI, mid high BMI, and extreme high BMI), BSQ, RSE, BDI, and age. We also tested all possible two-way interaction terms. The final model was optimized as described earlier. The detailed outcome for this statistical model is shown in the bottom half of Table 2. It shows that only adaptation and BSQ account for variance in VAS. We did not find a statistically significant interaction between adaptation and BSQ ($F(4,160) = 0.93$, $p = .45$). Post-hoc pairwise comparisons, controlled for multiple comparisons, showed that the main effect of adaptation was driven by statistically significant differences in VAS scores between: Actual BMI and Extreme Low BMI ($t(156) = 2.44$, $p = .02$), Actual BMI and Extreme High BMI ($t(156) = -2.95$, $p = .004$), and Mid High BMI and Extreme High BMI ($t(156) = -2.13$, $p = .03$). Despite these effects being statistically significant, nevertheless they constitute small effect sizes. The largest percentage increase in VAS we observed was between the Actual BMI adaptation level and the Extreme High BMI level, and this constituted only ~6%. By comparison, the percentage increase in body size estimation scores between the Extreme Low BMI adaptation level and the Extreme High BMI level was greater than ~1000%. Nevertheless, to be sure that there was no confounding effect of mood change (indexed by the VAS) on the body size estimation scores, we re-ran the first linear mixed effect model, but this time included VAS as an additional covariate. We found no statistically significant improvement to the model fit and no significant main effect of VAS on body size estimation.

Adaptation strength coded as a continuous variable

In the second analysis, we treated the strength of the adapting stimulus as a continuous variable and included participants' BMI as a covariate. Owing to the non-normal distribution of adaptation strength, we calculated bootstrap linear mixed effect models using PROC MIXED (SAS v9.4) together with a bootstrap wrapper (Adams, 2018) with which we resampled the data 10,000 times. Table 5 shows that we replicated the statistically significant fixed effects of BSQ and adaptation strength even when participant BMI was controlled. Critically, the 95% CI for the interaction between BSQ and adaptation strength straddled zero, suggesting that this interaction is not statistically robust. Figure 5b illustrates the model outcome. The scatterplot shows the raw data, each point colour coded according to whether the participant's BSQ score fell within the lowest third (green, M = 63.39, SD = 10.53), middle third (orange, M = 106.78, SD = 12.70), or upper third (purple, M = 144.13, SD = 13.70) of the range of BSQ scores within our data. The regression lines represent regressions of the marginal means predicted from the linear mixed effect models, calculated separately for the three BSQ ranges. Each line is shown with its 95% confidence interval. Together, the regression lines confirm a positive relationship between percentage error and adaptation strength, with an intercept controlled by BSQ.

False discovery rate

We note that following all the analyses described above, a total of 24 p-values are reported. This raises the question whether our analyses may have been inflated by Type I errors. We therefore use PROC MULTTEST (SAS v9.4) to compute the false discovery rate (FDR) for each p-value

(Benjamini & Hochberg, 1995). In no instance did a *p*-value that was already statistically significant at $p < .05$ have a FDR at $p \geq .05$.

Discussion

In this study, we have used a high-level adaptation paradigm to distinguish between two models of the relationship between attitudinal and perceptual body image. In the first model, these are meaningfully separate, statistically independent components of the body image construct. The second model suggests that visual tasks which purport to measure perceptual body image are really visual alternatives to the usual psychometric measures of attitudinal body image. In short, these visual tasks are a proxy for attitudinal body image measurements.

If the first, "independence" model were true, a regression of percentage error in body size estimation on the strength of the adapting stimulus should have a positive slope. In addition, the intercept of this regression line should be proportional to attitudinal measures: elevated body image concerns contribute a fixed amount to body size over-estimation (cf. Cornelissen et al., 2015 & 2017; Irvine et al., 2018). Therefore, plots of the adaptation effect in different observers, each of whom obtains a different score on body attitude, should produce a set of regression lines that have a positive slope and are *parallel* to each other. If the second model were true (i.e., vision as a proxy for attitude), following the logic of Social Comparison Theory (Festinger, 1954), the regression of percentage-error in body size estimation on the strength of the adapting stimulus should show negative slopes, with a linear interaction between the strength of the adapting stimuli and body attitude.

We analysed the adaptation data in two ways, once treating adaptation strength as a class variable and a second time treating adaptation strength as a continuous variable. Both analyses showed that: i) a regression of post-adaptation percentage error in body size estimation on the strength of the adapting stimuli had a positive slope, ii) increasing body image concerns indexed by the BSQ systematically increased the intercept for this regression, iii) any shift in body attitude (indexed by VAS scores) triggered by adaptation was detectable but ~100 times smaller than changes in body size estimation, and iv) there was no evidence for an interaction between the strength of the adapting stimulus and attitudinal body image on post-adaptation percentage error in body size estimation. Moreover, model selection using the Akaike (AIC) and Bayesian (BIC) information criteria (Wagenmakers and Farrell, 2004) showed that the evidence in favour of the no interaction model versus the model with interaction was, respectively, ~13 times and ~370 times stronger. Therefore, we conclude that this study provides strong support for the independence model.

Why does this matter?

AN is a serious mental illness effecting up to 1% of the female population in western societies, where the long-term mortality rate has been estimated to be as high as 10% (Berkman, Lohr, & Bulik, 2007). A distorted evaluation of personal body size, or body image distortion (DSM-V, 2013), is one of the central diagnostic criteria for AN, and is also a key element of psychological models of the disorder (Cash & Deagle, 1997; Fairburn, Cooper, & Shafran, 2003). The persistence of body image distortion predicts the rate of relapse (Channon & DeSilva, 1985; Slade & Russell, 1973) which has been estimated to be as high as 31% (Berends, Boonstra, & van Elburg, (2018). While some studies have shown that women with AN under-estimate their body size (Meerman, 1983; Mölbert et al. 2018), or even show performance in size estimation tasks equivalent to non-eating-disordered controls (Fernández, Probst, Meerman, & Vandereycken, 1994; Meermann, 1983), most studies have found that patients with AN overestimate their body size (Gardner & Bokenkamp, 1996; Probst, Vandereycken, Van Coppenolle, & Pieters, 1998; Slade & Russell, 1973; Tovée, Benson, Emery, Mason, & Cohen-Tovée, 2003). In the light of our evidence that attitudinal and perceptual body image are independent of each other, how might body size over-estimation in AN be explained?

Most explanations for body size over-estimation in AN are unidimensional. Proposed mechanisms start from the premise that somewhere in the system a signal has been exaggerated or magnified in a way that leads the sufferer to believe that they are bigger than is objectively true. Probably the least likely explanation of this sort is a disturbance of low-level visual processing (cf. Lawrence, Dowson, & Foxall, 2003; Moschos, Gonidakis, Varsou, Markopoulos, Rouvas, Ladas, et al., 2011). As we have seen, Smeets et al (1999) showed that sensitivity to small differences in size when pairs of bodies are compared (indexed by d-prime) are equivalent for women who have AN and healthy controls, and a similar conclusion was reached in another signal detection analysis carried out by Gardner and Moncrieff (1988). Moreover, if low level visual perceptual processes were disturbed in individuals with AN, then these disturbances should also apply to the perception of non-body objects, which they do not (e.g., Garner, Garfinkel, Stancer, & Moldofsky, 1976; Slade & Russell, 1973; Urgesi, Fornasari, Perini, et al., 2012). In addition, the problem should apply equally to judgements about an observers' own body as well as others' bodies. Yet, women with AN generally tend to overestimate their own body size, but do not do so for other persons or objects (Bowden, Touyz, Rodriguez, Hensley, & Beumont, 1989; Guardia, Conversy, Jardri, Lafargue, Thomas, et al., 2012; Slade & Russell, 1973).

An alternative unidimensional explanation was proposed by Smeets (1999), according to which: "*… the disturbance occurs at the stage of imagery. Because she thinks she is fat, the individual with anorexia nervosa (most often a female) constructs a visual image of herself as fat (a top-down approach). In recent theories of visual imagery, such as that of Kosslyn (1980, 1994), visual imagery is regarded as a process that involves not only visual representations, but also propositional (language-like, not visual) representations. So, every time an image is generated, it is reconstructed from memory, a process in which associated thoughts (or feelings) may affect the resulting image"*. In our view, this formulation seems to merge the attitudinal and perceptual components of body size estimation and is consistent with the "vision as proxy for attitude" hypothesis in the current study. According to this hypothesis, participants with AN would effectively be using the visual medium of a body size estimation task to cartoon their psychological distress. In the light of the present results, we would argue that this is at best an incomplete explanation because it does not permit an independent role for perceptual body image.

An alternative account of body size over-estimation in AN

Here we offer a new alternative account for body size over-estimation in AN. An important difference from the previous two explanations is that it is no longer unidimensional. Instead, it requires the comparison between *two* psychological magnitudes, one of which has been reduced relative to the other. Specifically, we propose that the necessary and sufficient conditions for body size over-estimation in AN could arise from a comparison between a reduced attitudinal magnitude and a normal perceptual magnitude. This is distinct from an isolated exaggeration of either attitudinal body image (e.g. "I feel fat") or perceptual body image (e.g. "I see a larger body in the mirror"), as is required by the unidimensional explanations. Here, we imagine the perceptual magnitude as equivalent to a self-estimate of body size of the kind measured in this study with the method of adjustment. It corresponds to the body shape and size that the person with AN believes they have, and it can be visualized in three-dimensional space like a volume. We imagine that the magnitude of the attitudinal component in AN corresponds to a composite index that can be derived from a number of psychological factors including body dissatisfaction, self-esteem and depression (Polivy & Herman, 2002; Mölbert et al., 2017; Kästner, Löwe, & Gumz, 2018; Mattar, Huas, Duclos, Apfel, & Godart, 2011). For example, in our own work across three studies, we have used the BDI, RSE, BSQ, and the Eating Disorders Examination Questionnaire (EDE-Q; Fairburn & Beglin, 1994) to measure these psychological factors in women with a history of eating disorders as well as healthy controls (a total of 272 participants across three studies) (Cornelissen, Bester, Cairns, Tovée, Cornelissen, 2015; Cornelissen, McCarty, Cornelissen, & Tovée, 2017; Irvine, McCarty, McKenzie, Pollet, Cornelissen, Tovée, & Cornelissen, 2018). In each study we ran a principal component analysis (PCA) on the psychometric responses and found that the data could be compressed into a *single* principal component (PC), reflecting variation in attitudes to body shape, weight and eating, self-esteem, and tendency to depression. For current purposes therefore, an individual's attitudinal magnitude can be thought of as their score along this PC: low scores reflect a combination of high body image concerns, low self-esteem, and depressed mood. High scores reflect the opposite; confidence in one's body, high self-esteem, and the absence of depressive thoughts. Put together therefore, we suggest that the necessary and sufficient conditions to explain body-size over-estimation in AN might be the comparison in the sufferer's mind between a "diminished" psychological self (i.e. reduced attitudinal magnitude), and a "normally" sized perceptual self (i.e. normal perceptual magnitude). In short, we suggest that the resultant calculation might lead the sufferer to perceive a normal sized body in the mirror. But, because what they see is much larger than what they feel they ought to have, or perhaps deserve, this leads them to conclude that they must be fat.

This proposal leads to the question whether such a comparison between two levels of representation about the body, one attitudinal and the other perceptual, is plausible. We argue that it is, based on recent evidence demonstrating dynamic interactions between attitudinal and perceptual body image representations, and the body schema, i.e., that part of the body representation which is critical for action-related guidance of the body (de Vignemont, 2010; Gallagher, 2006; Head & Holmes, 1912; Longo & Haggard, 2010). Irvine et al. (2018) used a motor imagery affordance task in which 100 healthy adult women judged the smallest gap between a pair of sliding doors that they could just pass through. The authors asked whether these gap estimates were sufficient to predict the size of the smallest gap that participants could actually pass through, or whether *both* perceptual and attitudinal body image information was required to make these predictions. They carried out a moderated mediation analysis which revealed a complex pattern of interdependence between these representational domains. For those with no, or only low-level psychological concerns, gap estimates predicted the size of the smallest passable gap directly. However, perceptual body image information *was* required to predict the smallest passable gap size – it had a mediating role – in those individuals who had heightened psychological concerns. Moreover, these interactions were specific to egocentric, self-referential body judgements, because no such effects were found for equivalent allocentric judgements about a yoga ball. The key implication from Irvine et al. (2018) and others (e.g., Alsmith, 2009; Kammers, Kootker, Hogendoorn, & Dijkerman, 2010; Newport, Pearce, & Preston, 2010; Pitron & de Vignemont, 2017) is that body representations not only constitute specific domains of encoded information (e.g., emotional, visual, proprioceptive) but also dynamic interactions between these domains. Similar ideas exist for computational network models of visual word recognition and reading, where nodes corresponding to orthographic, phonological and semantic representations of words are densely interconnected and interact with each other (Perry, Ziegler, & Zorzi, 2007).

Critically, this explanation of body estimation permits a normal sized perceptual body image even in individuals with AN to give rise to the percept that they are fat, provided only that their psychological sense of themselves has been "diminished". However, as Cornelissen et al. (2015, 2017) have shown by using yes-no and method of adjustment body size estimation tasks with standard models as well as 3D avatars, body size over-estimation also depends on the current BMI of the observer in women who have a history of AN. As their BMIs increase towards normal levels and beyond, body size over-estimation, i.e., the difference between actual BMI and BMI estimated from the body size estimation tasks, rapidly increases and is associated with dramatic reductions in sensitivity to differences in body size. This means that body size over-estimation in such individuals may result from the comparison between an increasingly exaggerated perceptual body image as well as a diminished psychological self.

Further evidence from intervention studies

Further evidence that indirectly supports this proposal comes from recent intervention studies by Gledhill, Cornelissen, Cornelissen, Penton-Voak, Munafò, & Tovée (2016) and Szostak (2018). In their first experiment, Gledhill et al. (2016) recruited women who had heightened body shape concerns, but no specific history of eating disorders. They used a novel perceptual training technique to shift observers' categorical boundaries for what, subjectively, they considered to be a thin versus a fat body. After four training sessions, one on each of four consecutive days, images of women that observers had previously categorized as fat were now judged as thin. This perceptual shift was followed by clinically meaningful reductions in observers' psychological concerns about body shape, weight and eating, and this persisted for two weeks post-training. Gledhill et al. (2016) found similar effects in a sample of women with a history of AN, although the perceptual changes took longer to emerge during training. In this case, the reductions in the anorexics' psychological concerns about body shape, weight and eating persisted for up to a month from initial testing. Using a more rigorous psychophysical testing procedure, Szostak (2018) replicated these results for women with heightened body shape, weight and eating concerns, but no specific history of eating disorders. Given the evidence for dynamic interactions between different levels of body representation (Irvine et al., 2018), we assume that the connections between attitudinal and perceptual body image can be driven to influence each other, in either direction. So, if women with AN who perceive their perceptual body image to be larger than their psychological self are retrained to treat a larger body as acceptable, this criterion shift may reduce the apparent discrepancy between the two. This may allow their attitudes to body shape, weight and eating to be normalized.

In conclusion, several authors have suggested that body size over-estimation in conditions like AN might be explained solely in terms of changes in attitudinal body image (Smeets, 1997 & 1999; Mergen, Keizer, Koelkebeck, van den Heuvel, & Wagner, 2018; Mölbert et al., 2018), and tasks that purportedly measure perceptual body image may in fact be visual proxies for estimates of attitudinal body image. Based on this study of women who experienced high-level adaptation to images of female bodies at different BMIs, our results suggest that both attitudinal and perceptual tasks do indeed measure independent aspects of body image and to fully characterise this problem, both components must be fully understood.

References

Adams, K., A. (2018) Bootstrap linear mixed-effects models using SAS® procedures. MWSUG - Paper HS-118.

Akaike, H. (1973). Information theory and an extension of the maximum likelihood principle. In B. N. Petrov & F. Caski (Eds.), *Proceedings of the Second International Symposium on Information Theory* (pp. 267-281). Budapest, Hungary: Akademiai Kiado.

Alsmith, A. J. (2009). Acting on (bodily) experience. *Psyche*, *15*, 82–99. Doi: 10.1016/j.concog.2017.06.006

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of General Psychiatry*, *4*, 561–571.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society. Series B (Methodological),* 57(1), 289–300. Doi: 10.2307/2346101

Berends, T., Boonstra, N., & van Elburg, A. (2018). Relapse in anorexia nervosa: a systematic review and meta-analysis. *Current Opinion in Psychiatry, 31,* 445-455.

Doi: 10.1097/YCO.0000000000000453

Berkman, N. D., Lohr, K. N., & Bulik, C. M. (2007). Outcomes of eating disorders: A systematic review of the literature. *International Journal of Eating Disorders*, *40*, 293–309. Doi: 10.1002/eat.20369

Blakemore, C. (1973). The baffled brain. In E. Gombricj and R. Gregory (Eds.) *Illusion in Nature and Art*. London: Duckworth.

Bowden, P. K., Touyz, S.W., Rodriguez, P. J., Hensley, R., Beumont, P. J. V. (1989). Distorting patient or distorting instrument? Body shape disturbance in patients with anorexia nervosa and bulimia. *British Journal of Psychiatry*, *155,* 196–201. Doi: 10.1192/bjp. 155.2.196.

Calder, A. J., Beaver, J. D., Winston, J. S., Dolan, R. J., Jenkins, R., et al. (2007). Separate coding of different gaze directions in the superior temporal sulcus and inferior parietal lobule. *Current Biology, 17,* 20–25.

Cash, T. F., & Deagle, E. A. (1997). The nature and extent of body-image disturbances in anorexia nervosa and bulimia nervosa: A meta-analysis. *International Journal of Eating Disorders*, *22*, 107-126.

Channon, S., & De Silva, W. (1985). Psychological correlates of weight gain in patients with anorexia nervosa. *Journal of Psychiatric Research, 19,* 267-271. Doi: 10.1016/B978-0-08-032704-4.50031-0.

Cooper, P. J., Taylor, M. J., Cooper, Z., & Fairburn, C. G. (1987). The development and validation of the Body Shape Questionnaire. *International Journal of Eating Disorders, 6*, 485-494.

Cornelissen, K. K., Bester, A., Cairns, P., Tovée, M. J., & Cornelissen, P.L. (2015). The influence of personal BMI on body size estimations and sensitivity to body size change in anorexia spectrum disorders. *Body Image, 13*, 75-85. Doi: 10.1016/j.bodyim.2015.01.001

Cornelissen, P. L., Johns, A., & Tovée, M. J. (2013). Body size overestimation in women with anorexia nervosa is not qualitatively different from female controls. *Body Image, 10*, 103–111. Doi: 10.1016/j.bodyim.2012.09.003.

Cornelissen, K. K., McCarty, K., Cornelissen, P. L., & Tovée, M. J. (2017). Body size estimation in women with anorexia nervosa and healthy controls using 3D avatars. *Scientific Reports, 7,* 15773. Doi: 10.1038/s41598-017-15339-z.

de Vignemont, F. (2010). Body schema and body image-Pros and cons. *Neuropsychologia, 48*, 669–680. Doi: 10.1016/j.neuropsychologia.2009.09.022.

Evans, C., & Dolan, B. (1993). Body Shape Questionnaire: derivation of shortened “alternate forms”. *International Journal of Eating Disorders*, *13*, 315-321. Doi: 10.1002/1098-108X(199304)13:3<315::AID-EAT2260130310>3.0.CO;2-3

Fairburn, C. G., & Beglin, S. J. (1994). Assessment of eating disorders: interview or self-report questionnaire? Eating Disorders, 16(4), 363-370. Doi: 10.1002/1098-108X(199412)16:4<363::AID-EAT2260160405>3.0.CO;2-#

Fairburn, C. G., Cooper, Z., & Shafran, R. (2003). Cognitive behaviour therapy for eating disorders: a “transdiagnostic” theory and treatment. *Behaviour Research and Therapy, 41*, 509–528. Doi:10.1016/s0005-7967(02)00088-8

Fernández, F., Probst, M., Meerman, R., & Vandereycken, W. (1994). Body size estimation and body dissatisfaction in eating disorder patients and normal controls. *International Journal of Eating Disorders*, *16*, 307-310.

Fernandez Aranda, F., Dahme, B., & Meermann, R. (1999). Body image in eating disorders and analysis of relevance: A preliminary study. *Journal of Psychosomatic Research*, *47*, 419–428.

Festinger, L. (1954). A theory of social comparison processes. *Human relations, 7,* 117-140.

Fox, C. J., Barton, J. J. S. (2007). What is adapted in face adaptation? The neural representations of expression in the human visual system. *Brain Res*, *1127,* 80– 89.

Frisby, J. P. (1979). *Seeing*. Oxford: Oxford University Press.

Gallagher, S., (2006). *How the body shapes the mind*. Oxford: Oxford University Press. Doi: 10.1093/0199271941.001.0001.

Gardner, R. M., & Bokenkamp, E. D. (1996). The role of sensory and nonsensory factors in body size estimations of eating disorder subjects. *Journal of Clinical Psychology, 52*, 3-15.

Gardner, R. M., & Moncrieff, C. (1988). Body image distortion in anorexics as a non-sensory phenomenon: A signal detection approach. *Journal of Clinical Psychology, 44*,101-107.

Gardner, R. M., Jones, L. C., & Bokenkamp, E. D. (1995). Comparison of three psychophysical techniques for estimating body-size perception. *Perceptual and Motor Skills, 80,* 1379-1390.

Gardner, R. M., & Brown, D. L. (2014). Body size estimation in anorexia nervosa: A brief review of findings from 2003 through 2013. *Psychiatry Research, 219(3)*, 407-410.

Garner, D. M., Garfinkel, P. E., Stancer, H. C., & Moldofsky, H. (1976). Body image disturbances in anorexia nervosa and obesity. Psychosomatic Medicine, 38, 327–336.

Gescheider, G. A. (1997). *Psychophysics: The Fundamentals (3rd ed.)*. New Jersey: Lawrence Erlbaum.

Gledhill, L. J., Cornelissen, K. K., Cornelissen, P. L., Penton-Voak, I. S., Munafò, M. R., & Tovée, M. J. (2016). An interactive training programme to treat body image disturbance. *British Journal of Health Psychology, 22*, 60–76. Doi: 10.1111/bjhp.12217

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

Guardia, D., Conversy, L., Jardri, R., Lafargue, G., Thomas, P., et al. (2012). Imagining one's own and someone else's body actions: Dissociation in Anorexia Nervosa. *PLoS ONE*, *7*: e43241. Doi: 10.1371/journal.pone.0043241

Head, H., & Holmes, G. (1912). Researches into sensory disturbances from cerebral lesions. *Lancet 179*, 1–4. Doi: 10.1016/S0140-6736(00)51693-6.

Health Survey for England (2003). National Centre for Social Research and University College London. Department of Epidemiology and Public Health. UK Data Archive, Colchester, Essex.

Health Survey for England (2008). National Centre for Social Research and University College London. Department of Epidemiology and Public Health. UK Data Archive, Colchester, Essex, UK.

Hummel, D., Rudolf, A., Untch, K., Grabhorn, R., & Mohr, H. (2012). Visual Adaptation to Thin and Fat Bodies Transfers across Identity. *Plos ONE, 7,* e43195. Doi: 10.1371/journal.pone.0043195

Irvine, K. R., McCarty, K., McKenzie, K., Pollet, T.V., Cornelissen, K. K., Tovée, M. J., & Cornelissen, P. L. (2018). Distorted body image influences body schema in individuals with negative bodily attitudes. *Neuropsychologia*. Doi: 10.1016/j.neuropsychologia.2018.11.015

Kästner, D., Löwe, B., & Gumz, A. (2018). The role of self-esteem in the treatment of patients with anorexia nervosa – A systematic review and meta-analysis. *International Journal of Eating Disorders*, 1-16. Doi: 10.1002/eat.22975

Kammers, M. P. M., Kootker, J. A., Hogendoorn, H., & Dijkerman, H. C. (2010). How many motoric body representations can we grasp? *Experimental Brain Research, 202*, 203-212. Doi: 10.1007/s00221-009-2124-7

Kosslyn, S. M. (1980) *Image and mind*. Cambridge, MA: Harvard University Press.

Kosslyn, S. M. (1994) *Image and brain: the resolution of the imagery debate*. Cambridge, MA: MIT Press.

Krantz, D. H. (1969). Threshold theories of signal detection. *Psychological Review*, *76*, 308–324.

Kreidler, S. M., Muller, K.E., Grunwald, G. K., Ringham, B. M., Coker-Dukowitz, Z. T., Sakhadeo, U. R. et al. (2013). GLIMMPSE: Online Power Computation for Linear Models with and without a Baseline Covariate. *Journal of Statistical Software, 54*, no. 10.

Lawrence, A. D., Dowson, J., & Foxall, G. L. (2003). Impaired visual discrimination learning in anorexia nervosa. *Appetite, 40*, 1, 85-89.

Longo, M. R., & Haggard, P., (2010). An implicit body representation underlying human position sense. *Proceedings National Academy of Sciences (USA), 29*, 11727–11732.

Mattar, L., Huas, C., Duclos, J., Apfel, A., & Godart, N. (2011) Relationship between malnutrition and depression or anxiety in Anorexia Nervosa: a critical review of the literature. *Journal of Affective Disorders*, *132*, 311-318. Doi: 10.1016/j.jad.2010.09.014

Meerman, R. (1983). Experimental investigation of disturbances in body image estimation in anorexia nervosa patients, and ballet and gymnastics pupils. *International Journal of Eating Disorders*, *2*, 91-100.

Mergen, J., Keizer, A., Koelkebeck, K., van den Heuvel, M. R. C., & Wagner, H. (2018). Women with Anorexia Nervosa do not show altered tactile localization compared to healthy controls. *Psychiatry Research, 267*, 446-454. Doi: 10.1016/j.psychres.2018.06.007

Mölbert, S. C., Thaler, A., Mohler, B. J., Streuber, S., Romero, J., Black, M. J., et al., (2018). Assessing body image in anorexia nervosa using biometric self-avatars in virtual reality: attitudinal components rather than visual body size estimation are distorted. *Psychological Medicine, 48*, 642–653. Doi: 10.1017/S0033291717002008.

Mölbert, S. C., Klein, L., Thaler, A., Mohler, B. J., Brozzo, C, Martus, P., Karnath, H-O., Zipfel, S. & Giel, K. E. (2017). Depictive and metric body size estimation in anorexia nervosa and bulimia nervosa: A systematic review and meta-analysis. *Clinical Psychology Review, 57*, 21-31. Doi: 10.1016/j.cpr.2017.08.005.

Moschos, M. M., Gonidakis, F., Varsou, E., Markopoulos, I., Rouvas, A., Ladas, I., & Papadimitriou, G. N. (2011). Anatomical and functional impairment of the retina and optic nerve in patients with anorexia nervosa without vision loss. *British Journal of Ophthalmology, 95*, 1128-1133.

Newport, R., Pearce, R., & Preston, C. (2010). Fake hands in action: embodiment and control of supernumerary limbs. *Experimental Brain Research, 204*, 385-95. Doi: 10.1007/s00221-009-2104-y.

Ng, M., Boynton, G. M., & Fine, I. (2008). Face adaptation does not improve performance on search or discrimination tasks. *Journal of Vision, 8*, 1–20.

Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: The CDP+ model of reading aloud. *Psychological Review, 114*, 273-315. Doi: 10.1037/0033-295X.114.2.273

Pitron, V., & de Vignemont, F. (2017). Beyond differences between the body schema and the body image: insights from body hallucinations. *Consciousness and Cognition, 53*, 115-121. Doi: 10.1016/j.concog.2017.06.006

Polivy, J., & Herman, C.P. (2002). Causes of eating disorders. Annual Review of Psychology, 53, 187-213.

Poulton, E. C. (1989). *Bias in Quantifying Judgements*. Hove, UK: Erlbaum.

Probst, M., Pieters, G., & Vanderlinden, J. (2008). Evaluation of body experience questionnaires in eating disorders in female patients (AN/BN) and nonclinical participants. *International Journal of Eating Disorders*, *41*, 657-665.

Probst, M., Vandereycken, W., Van Coppenolle, H., & Pieters, G. (1998). Body size estimation in anorexia nervosa patients: the significance of overestimation. *Journal of Psychosomatic Research, 44,* 451-456.

Rosenberg, M. (1965). *Society and the adolescent self-image*. Princeton, NJ: Princeton University Press.

Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics*, *6,* 461-464.

Skrzypek, S., Wehmeier, P. M., & Remschmidt, H. (2001). Body image assessment using body size estimation in recent studies on anorexia nervosa. A brief review. *European Child & Adolescent Psychiatry, 10,* 215-221.

Slade, P., & Russell, G. (1973). Awareness of body dimensions in anorexia nervosa: cross-sectional and longitudinal studies. *Psychological Medicine*, *3*, 188-199. Doi: 10.1017/s0033291700048510

Smeets, M. A. M., (1997). The rise and fall of body size estimation research in anorexia nervosa: a review and reconceptualization. *European Eating Disorders Review, 5*, 75–95. Doi: 10.1002/(SICI)1099-0968(199706)5:2<75::AID-ERV190>3.0.CO;2-A.

Smeets, M. A. M., Ingleby J. D., Hoek, H. W., & Panhuysen, G. E. M. (1999). Body size perception in anorexia nervosa: a signal detection approach. *Journal of Psychosomatic Research, 46*, 465-477.

Stephen, I.D., Hunter, K., Sturman, D., Mond, J., Stevenson, R.J., & Brooks, K.R. (2018). Experimental manipulation of visual attention affects body size adaptation but not body dissatisfaction. *International Journal of Eating Disorders, 52,* 79-87. DOI: 10.1002/eat.22976

Stephen, I.D., Sturman, D., Stevenson, R.J., Mond, J., & Brooks, K.R. (2018). Visual attention mediates the relationship between body satisfaction and susceptibility to the body size adaptation effect. *PLoS One*. Doi: 10.1371/journal.pone.0189855

Sturman, D., Stephen, I.D., Mond, J., Stevenson, R.J., & Brooks, K.R. (2017). Independent aftereffects of fat and muscle: Implications for neural encoding, body space representation, and body image disturbance. *Scientific Reports, 7*, 40392. Doi: 10.1038/srep40392

Szostak, N. M. (2018). *Negative body image and cognitive biases to body size*. (Doctoral dissertation). Retrieved from: https://hydra.hull.ac.uk/resources/hull:16444

Tovée, M. J., Benson, P. J., Emery, J. L., Mason, S. M., & Cohen-Tovée, E. M. (2003). Measurement of body size and shape perception in eating-disordered and control observers using body-shape software. *British Journal of Psychology, 94,* 501-516. Doi: 10.1348/000712603322503060

Urgesi, C., Fornasari, L., Perini, L., Canalaz, F., Cremaschi, S., Faleschini, L., & Brambilla, P. (2012). Visual body perception in anorexia nervosa. *International Journal of Eating Disorders, 45*, 501-511.

Wagenmakers, E-J., & Farrell, S.J. (2004) AIC model selection using Akaike weights. *Psychonomic Bulletin & Review, 11 (1)*, 192-196.

Webster, M. A., Kaping, D., Mizokami, Y., Duhamel, P. (2004). Adaptation to natural facial categories. *Nature, 428,* 557–561.

Webster, M. A. (2011). Adaptation and visual coding. *Journal of Vision*, *11*, 1–23.

Winkler, C., & Rhodes, G. (2005). Perceptual adaptation affects attractiveness of female bodies. *British Journal of Psychology, 96*, 141-154. Doi: 10.1348/000712605x36343. x36343

Table 1. Characteristics of 40 female participants.

	M	*SD*	Range	
			Actual	Potential
Age (years)	23.75	6.54		
BMI (weight/height^2)	24.43	4.96		
BDI	7.90	5.89	0 – 22	0 – 63
RSE	28.88	3.52	21 – 37	0 – 40
BSQ-34	89.30	34.82	39 – 169	34 – 204

Note: BDI= Beck Depression Inventory; BMI= Body Mass Index; BSQ-34= 34-item Body Shape Questionnaire; RSE= Rosenberg Self-Esteem Scale.

Table 2. Outcome of the linear mixed effect modelling.

Model Parameters	*F*-value (*DF*)	*Z*-value	*p*-value	Parameter estimate	Parameter 95% CI	-2Log likelihood
1) Percentage error in BSE						
Null Model						1441.2
Full Model						1361.4
Fixed Effects:						
Adaptation	21.42 (4, 156)		<.001	1) -9.35	-11.79 – -6.90	
				2) -8.73	-11.18 – -6.28	
				3) -5.67	-8.12 – -3.22	
				4) -2.21	-4.66 – 0.24	
BSQ	6.28 (1, 38)		.01	0.13	0.025 – 0.24	
Random Effect:						
Subject variance		4.15	<.001	122.28		
2) VAS						
Null Model						497.9
Full Model						492.9
Fixed Effects:						
Adaptation	2.85 (4, 156)		.03	1) -0.068	-0.32 – 0.19	
				2) -0.19	-0.45 – 0.067	
				3) -0.39	-0.64 – -0.13	
				4) -0.28	-0.53 – -0.020	
BSQ	14.19 (1, 38)		<.001	-0.022	-0.034 – -0.010	
Random Effect:						
Subject variance		4.18	<.001	1.58		

Table 3: Akaike and Bayesian information criterion weights

Model	AIC_i	Δ_i(AIC)	w_i(AIC)	BIC_i	Δ_i(BIC)	w_i(BIC)
No interaction	1384.2	0	0.9286	1397.7	0	0.9973
With interaction	1389.3	5.1	0.0724	1409.5	11.8	0.0027
Intercept only	1450.3	66.1	0.0000	1455.4	57.7	0.0000

Table 4. Pearson correlations between psychometric measures and VAS scores.

			VAS scores		
	Ext Low BMI	Mid Low BMI	Actual BMI	Mid High BMI	Ext High BMI
BDI	-0.43**	-0.44**	-0.53***	-0.41**	-0.52***
BSQ	-0.52***	-0.45**	-0.54***	-0.42**	-0.53***
RSE	0.38*	0.29	0.36*	0.25	0.35*

NB: * = p<.05; **= p<.01; ***= p<.001

Table 5. Bootstrap linear mixed effect model estimates with 10,000 resamples

Model Parameters	Parameter estimate	*SE*	95% CI
Fixed Effects:			
Adaptation strength	0.48	0.11	0.26 – 0.71
BSQ	0.21	0.044	0.13 – 0.30
BMI	-0.54	0.11	-0.76 – -0.32
Adaptation strength × BSQ	-0.0020	0.0013	-0.0046 – 0.00064
Random Effect			
Subject variance	117.51	9.23	99.80 – 135.88

Figure Legends

Figure 1: a) shows the relationship between participants' BMI (x-axis) and their subjective estimate of body size (PSE) separately for women with a history of AN (white) and healthy controls (black) (from Cornelissen et al., 2015). The dotted black line represents the line of equality, where PSE matches BMI perfectly. The impact of psychometric performance on these relationships is illustrated by the separate lines for each group: i.e., the data are plotted for PSYCH (a latent variable derived from a principal components analysis of questionnaires assessing attitudes to body shape, eating, depression and self-esteem) at + 1 SD, dashed lines, and – 1 SD, solid lines. b) Sketch graph to show predicted effects of adaptation for the "independence" hypothesis. The y-axis represents percentage error in post-adaptation body-size estimation. Negative values represent under-estimation and positive values over-estimation. The x-axis corresponds to the size of the adapting stimulus relative to the body size of the observer. For Sketch graphs b), c), and d), the adaptation effects are shown separately for low (circles), medium (triangles), and high (squares) body image concerns. c) Sketch graph to show predicted effects of adaptation for the "perception as proxy for attitude" hypothesis. d) Sketch graph to show predicted effects of adaptation for the "perception as proxy for attitude" hypothesis allowing for a saturation effect in individuals with moderate or high body image concerns.

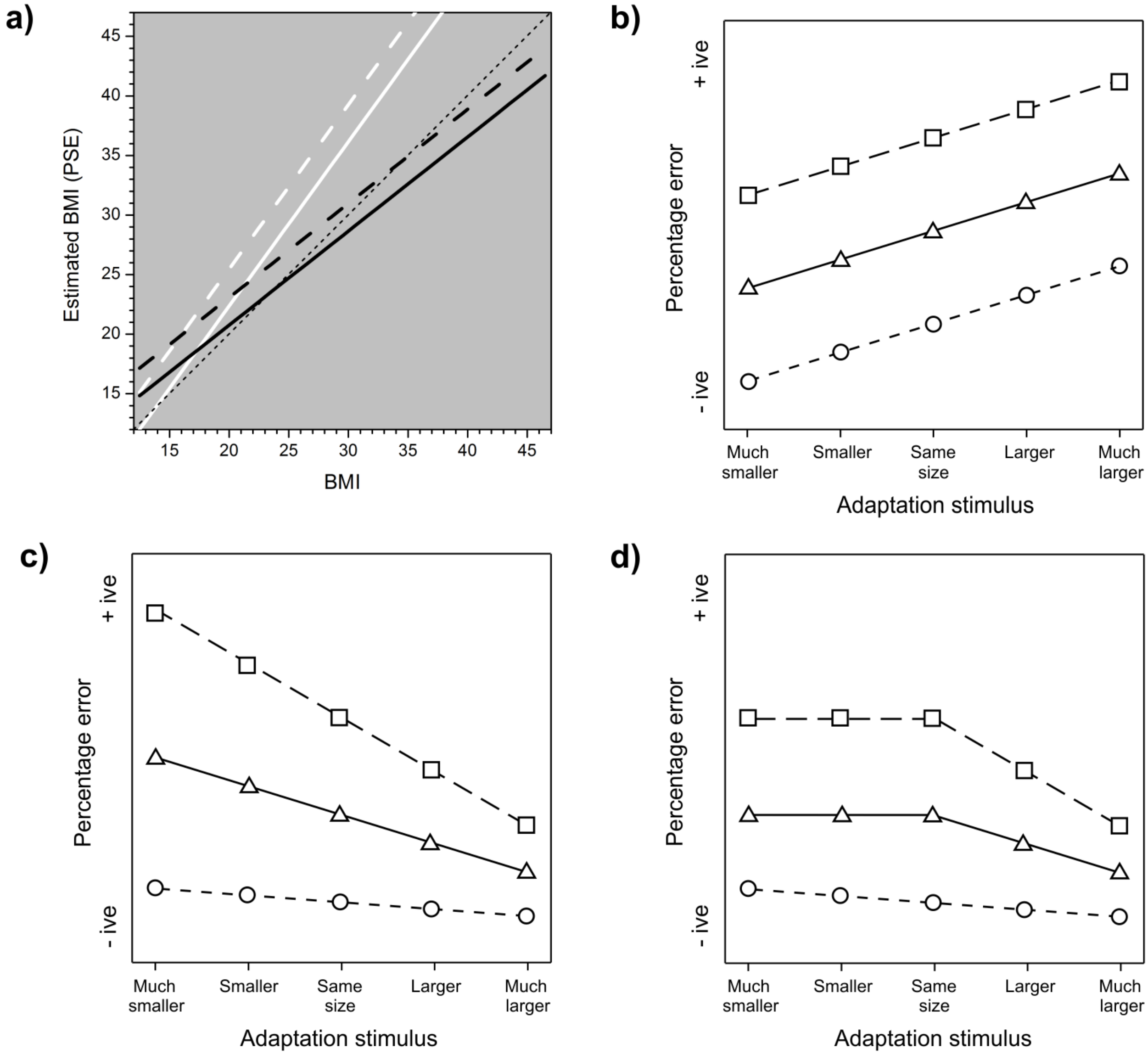
Figure 2: Body shape changes in the MoA task for the standard model stimulus as the slider control is moved from left to right through screenshots A, B, C, & D.

Figure 3: Flow diagram to represent the experimental procedure.

Figure 4: Boxplots of a) percentage error in body size estimation and b) the VAS responses as a function of the BMI range of the adapting stimuli.

Figure 5: a) Plots of LSmean percentage error in post-adaptation body size estimation predicted from the optimized model using adaptation strength coded as a class variable. The LSmeans are computed

separately for three levels of BSQ: 40 (gray squares), 100 (empty circles) and 160 (black triangles). The error bars represent 95% confidence intervals. Data points at each BSQ level are offset to avoid overlap of the error bars. b) Scatterplot of percentage error in post-adaptation body size estimation as a function of adaptation strength. Individual data points are colour coded according to whether the participant's BSQ score fell within the lowest third (green), middle third (orange), or upper third (purple) of the range of BSQ scores within our data. The regression lines represent regressions of the marginal means predicted from the linear mixed effect models, calculated separately for the three BSQ ranges. Each line is shown with its 95% confidence interval.



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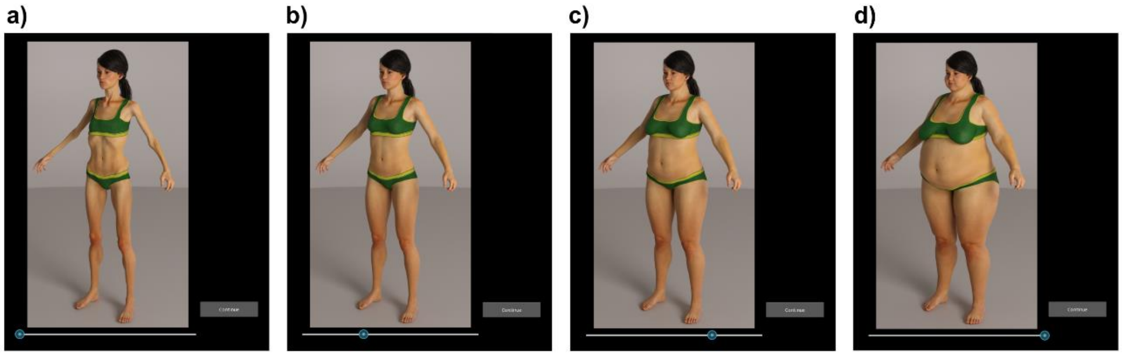

Figure 2: Body shape changes in the MoA task for the standard model stimulus as the slider control is moved from left to right through screenshots a), b), c), & d).

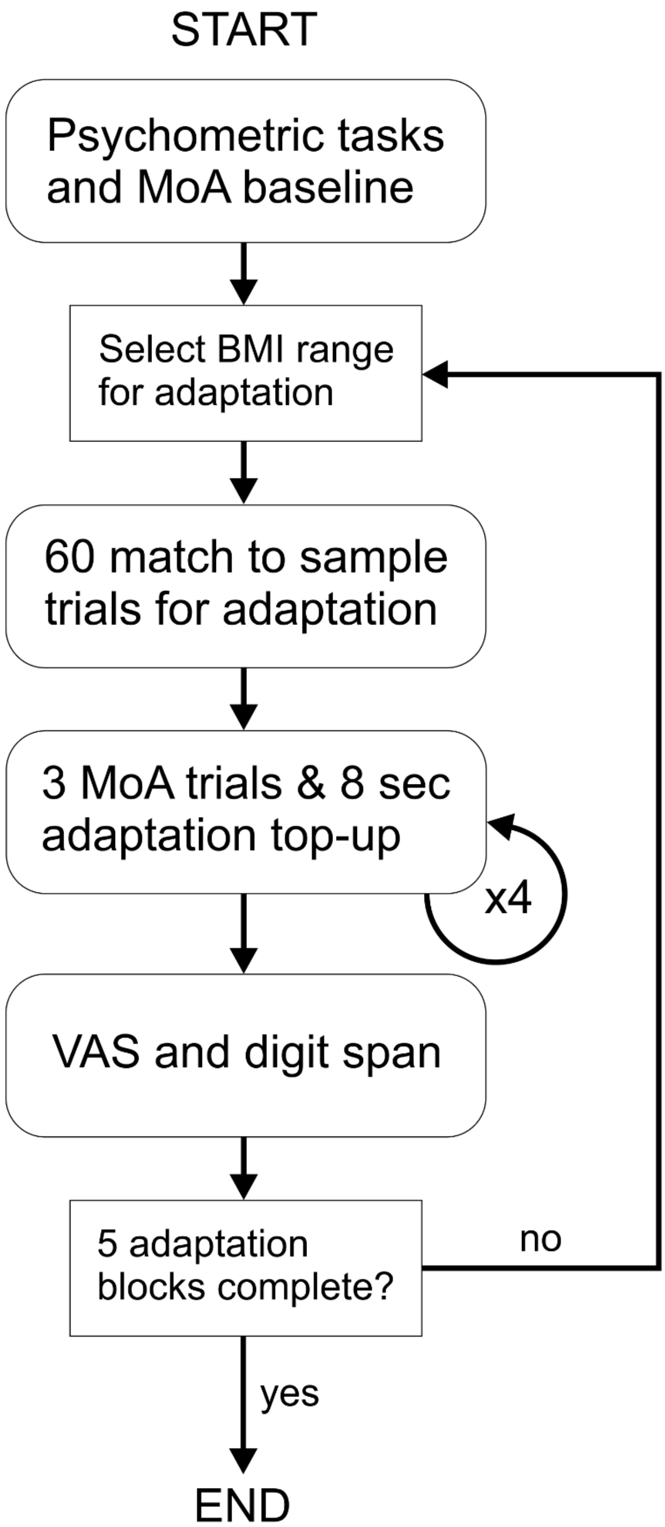

Figure 3: Flow diagram to represent the experimental procedure.

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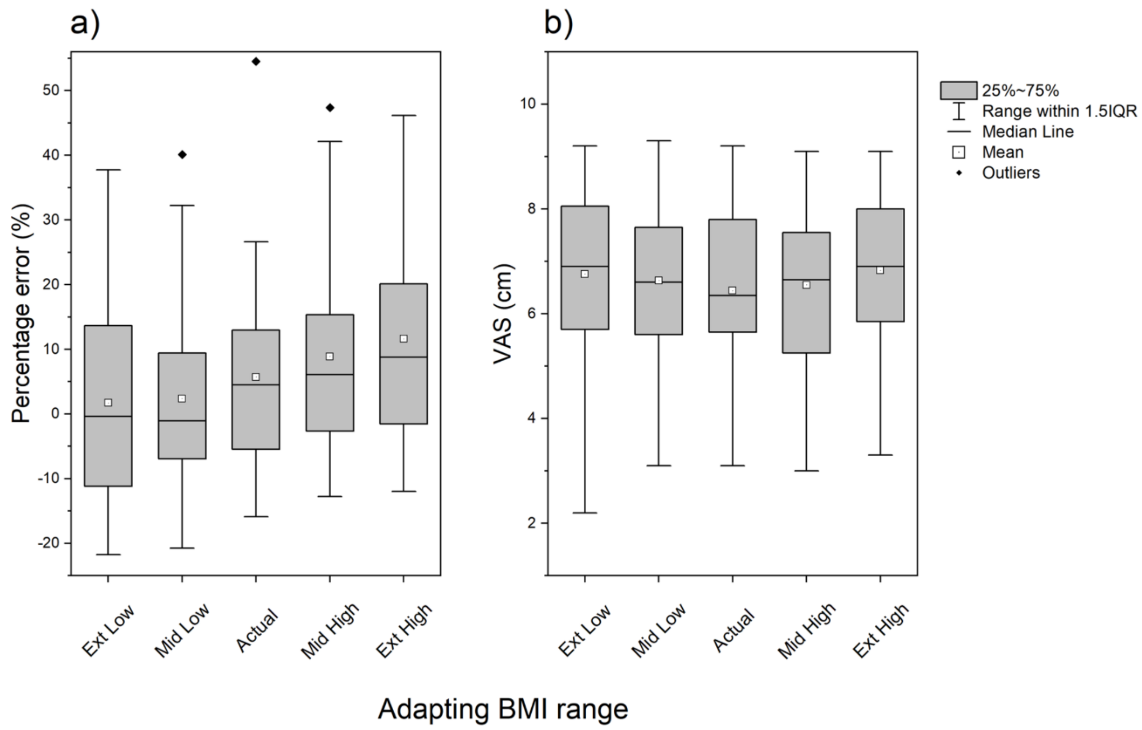

Figure 4: Boxplots of a) percentage error in body size estimation and b) the VAS responses as a function of the BMI range of the adapting stimuli.

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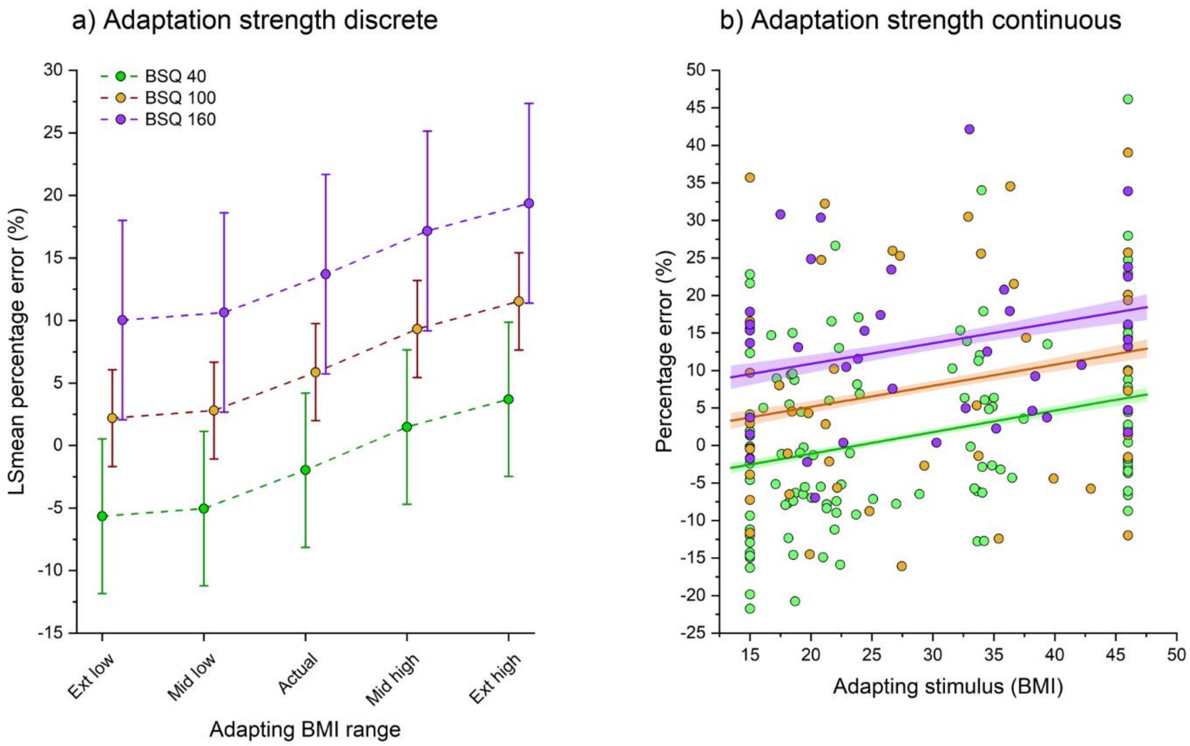

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